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Development of Metal/Ceramic Nanocomposite Powder and Consolidation to Bulk Nanocomposite Components with Retained Nanostructures

Instrument Innovation: A Plasma Shroud for Oxidation Prevention During Air Plasma Spray

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Submitted By

Sudipta Seal, Ph.D.

Advanced Materials Processing and Analysis Center (AMPAC), and
Mechanical, Materials, Aerospace Engineering
University of Central Florida
Eng I, Suite #381, 4000 Central Florida Blvd.,
Orlando, FL 32816.

Dr.A.K. Vasudevan

Program Manager
Scientific Officer, Materials Division

AMPAC
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6. AUTHOR(S)

Seal, Sudipta; Georgieva, Petya; Rea, Keith
Viswanathan Venkatachalapathy

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

UCF Office of Research
12443 Research Pkwy, Suite 207
Orlando, FL 32826

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14. ABSTRACT

An instrument innovation has been developed that enables for the minimization of oxidation during Air Plasma Spray (APS). Oxidation is limited due to the creation of a three-part copper shroud that utilizes a custom-fit mounting plate that is affixed to the SG-100 APS plasma gun. Due to the separation of the ambient environment from the plasma flame and the particles traveling through it, this process has been deemed Shrouded Air Plasma Spray or SAPS. Shrouding the plasma flame and the molten particles holds much promise for the minimization of porosity, oxidation, and other debilitating material phenomenon that occurs at the high temperatures and rapid solidification environment that is used for the development of bulk nanostructured components. This shroud design has been experimentally tested and meets all APS spraying parameters.

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Content

Summary of Previous Report

- Coinciding with earlier reports, the most recent report utilized derived agglomerated Al_2O_3 powder feedstock and documented experimental results relating the density of bulk plasma formed nanostructured components to the plasma spray parameters, most notably the standoff distance and enthalpy (heat energy) input.

- A mechanical screening process was developed and used to rapidly manufacture asymmetric nanostructured ceramic components.

- The density of the nanostructured component and the standoff distance parameter during air plasma spray were shown to have an inverse relationship in this specific ceramic system.

- Higher enthalpy input was created by raising the secondary gas flow rate parameter, thereby leading to a higher rate of disintegration of the agglomerate feedstock in the plasma flame and an increase in coherent interface formation (reduction of porosity).

- Transmission Electron Microscopy experimentally confirmed the retention of nanostructures, a decrease in localized porosity, and the overall relationship to the spray drying (of agglomerate feedstock) temperature parameter.

Air Plasma Spray (APS) Shroud

1. **Purpose and Function**

Air plasma spray has multiple advantages over other plasma forming techniques, especially when taking into consideration the formation and retention of nanoscaled structures. Among these are the ability to have a high rate of undercooling (rapid solidification) necessary for homogenous nucleation and solidification, the lack of large complex and costly vacuum equipment, and a higher degree of reproducibility due to the increased robotic arm mobility. However, APS also has some debilitating disadvantages for processing bulk nanostructured metallic components. Whereas, the feedstock and the plasma flame are open to the ambient environment during processing, there is large tendency for a molten metallic particle to become oxidized or trap vacancies and create unwanted porosity during melting and rapid solidification.

Because oxidation and vacancy entrapment (in some metallic systems) leads to a decrease in the bulk mechanical properties of the component it becomes necessary to develop a method of reducing or completely eliminating the oxygen in the plasma spray environment. Vacuum Plasma Spray (VPS) is one such route, but has a cost upwards of $2 million and is bulky for large-scale manufacturing purposes. For manufacturing metallic components, the disadvantages of VPS processing outweigh its major advantage of limiting oxidation. This report documents the development of a mechanical means of shrouding the plasma spray processing of metallic components for the reduction of in-flight and solidification oxidation. Since the plasma spray is no longer completely open to the elements (air and humidity) we have termed this processing route to be described Shrouded Air Plasma Spray (SAPS).

2. **Mechanical Design Concepts**

For eliminating the contact of oxygen and humidity with the plasma flame and ensuing depositing particles it is necessary to shroud the particles path in the flame from their origin to a length sufficient to eliminate the oxidation phenomenon of metal matrix and nanomaterials. To do this requires constructing a concealing partition that is also able to withstand the heat transfer undergone during processing without failing. For this purpose we designed and manufactured a three-part tube encasement of oxygen-free copper. The material selection of oxygen-free copper was based on its high thermal conductivity (383-391 W/m-K). An overall isometric rendering of the machined shroud assembly is shown in Figure 1 and will be discussed piece by piece for design advantages.

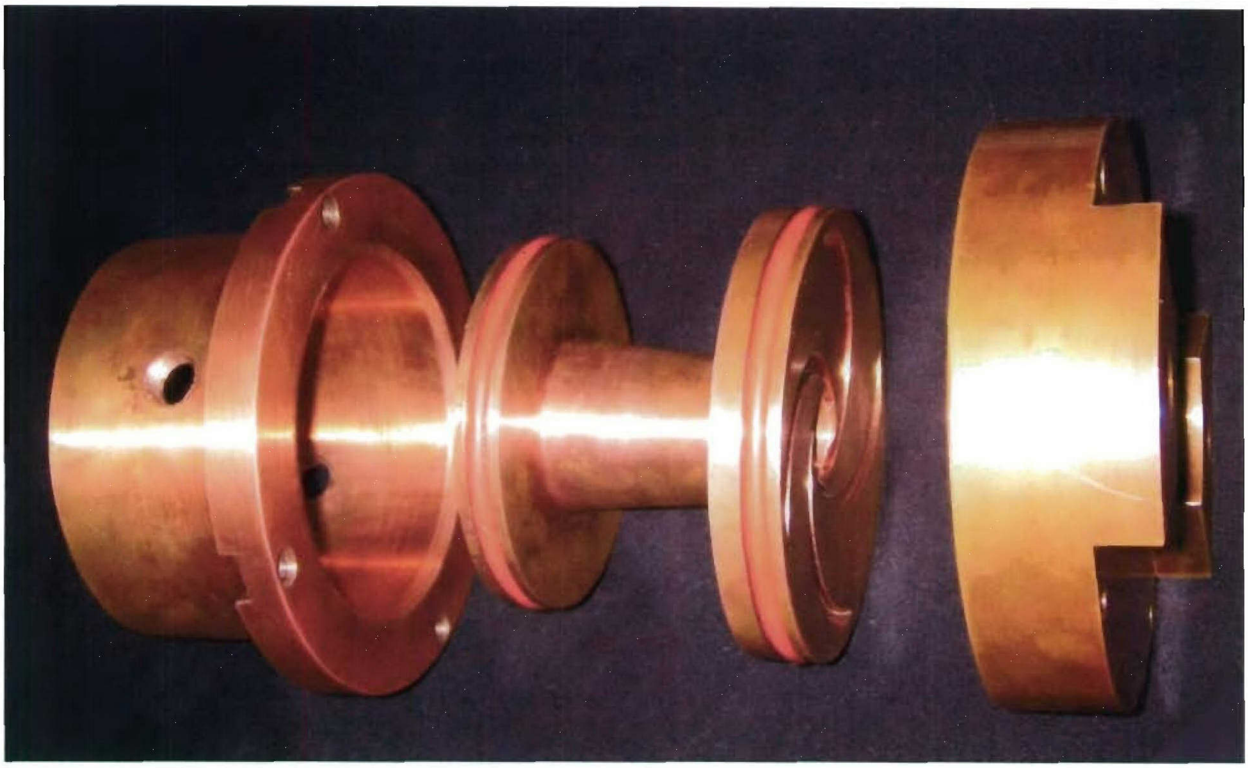

Figure 1. The three part plasma shroud assembly for the SG-100 air plasma spray gun.

A three part design was chosen for easy removal from the SG-100 (Praxair-TAFA Surface Technologies, Inc.) APS gun for cleaning and maintenance. This design was also conducive for producing the internal circulating water-cooling cavity that is depicted in the schematic of Figure 2.

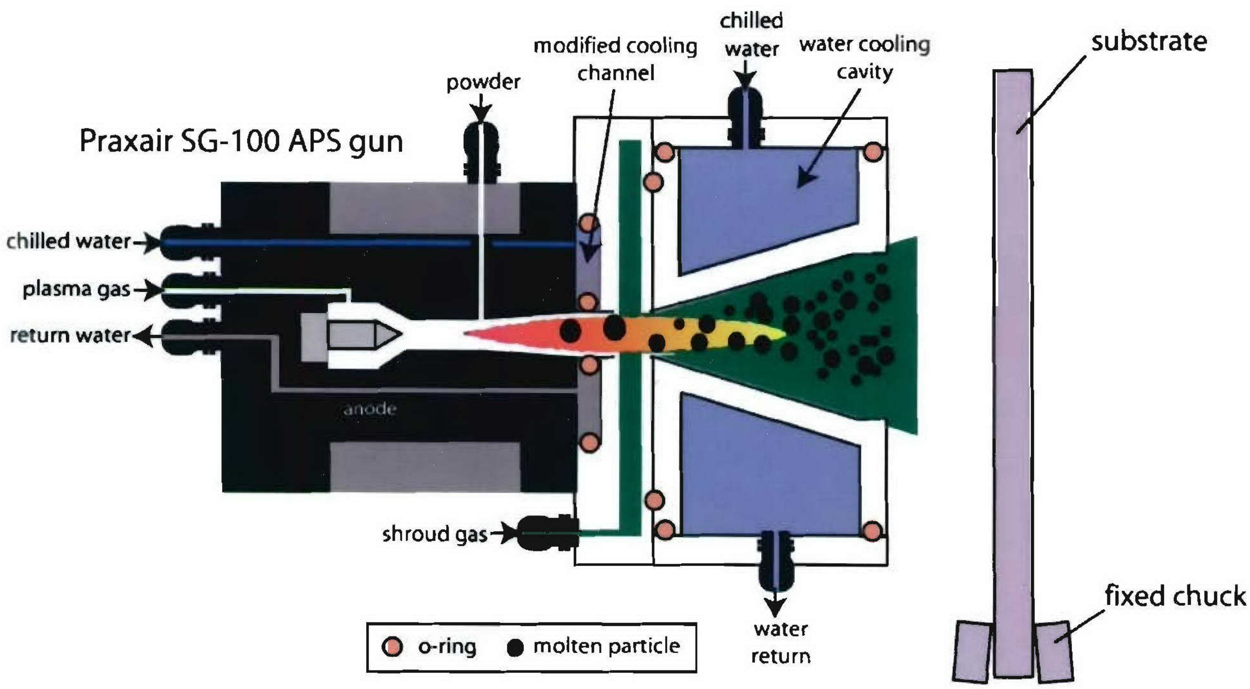

Figure 2. Simplified cross-section view of plasma shroud apparatus attached to SG-100 APS gun.

The Praxair SG-100 APS gun already has a two-piece design with a removable front plate for cleaning a small circulating cooling channel. The cooling channel is sealed by two o-rings and the plate is connected by three socket head cap screws. To utilize the existing cooling apparatus, a similar cooling scheme was designed that takes the place of the SG-100 faceplate and also enables for the attachment of the remainder of the shroud assembly. A working drawing of the SG-100 APS gun taken from the User's manual [1] is given in Figure 3. An orthographic view of the designed mounting plate can be seen in Figure 4.

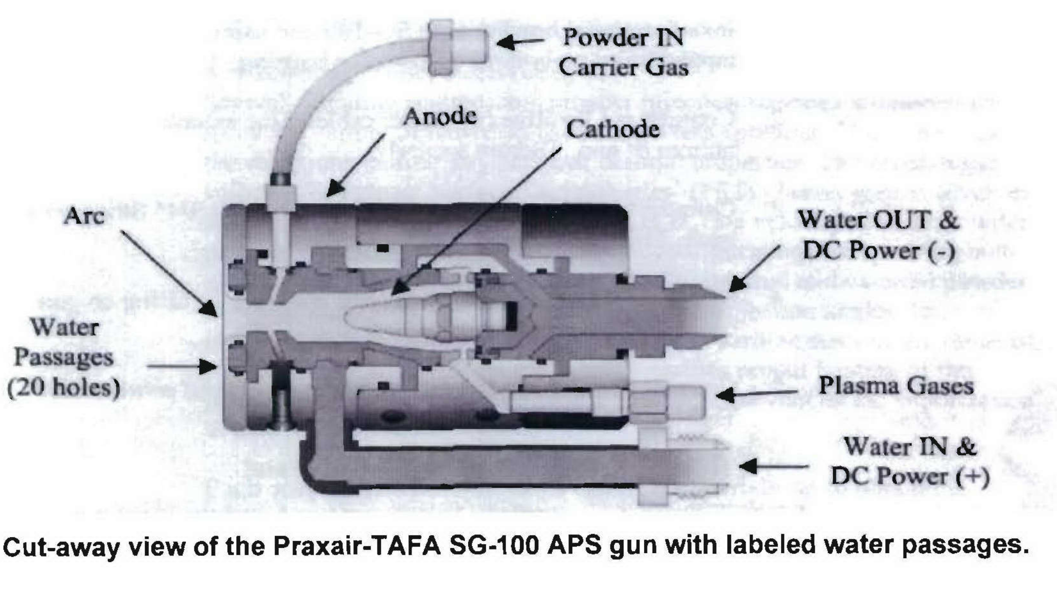

Figure 3. Cut-away view of the Praxair-TAFA SG-100 APS gun with labeled water passages.

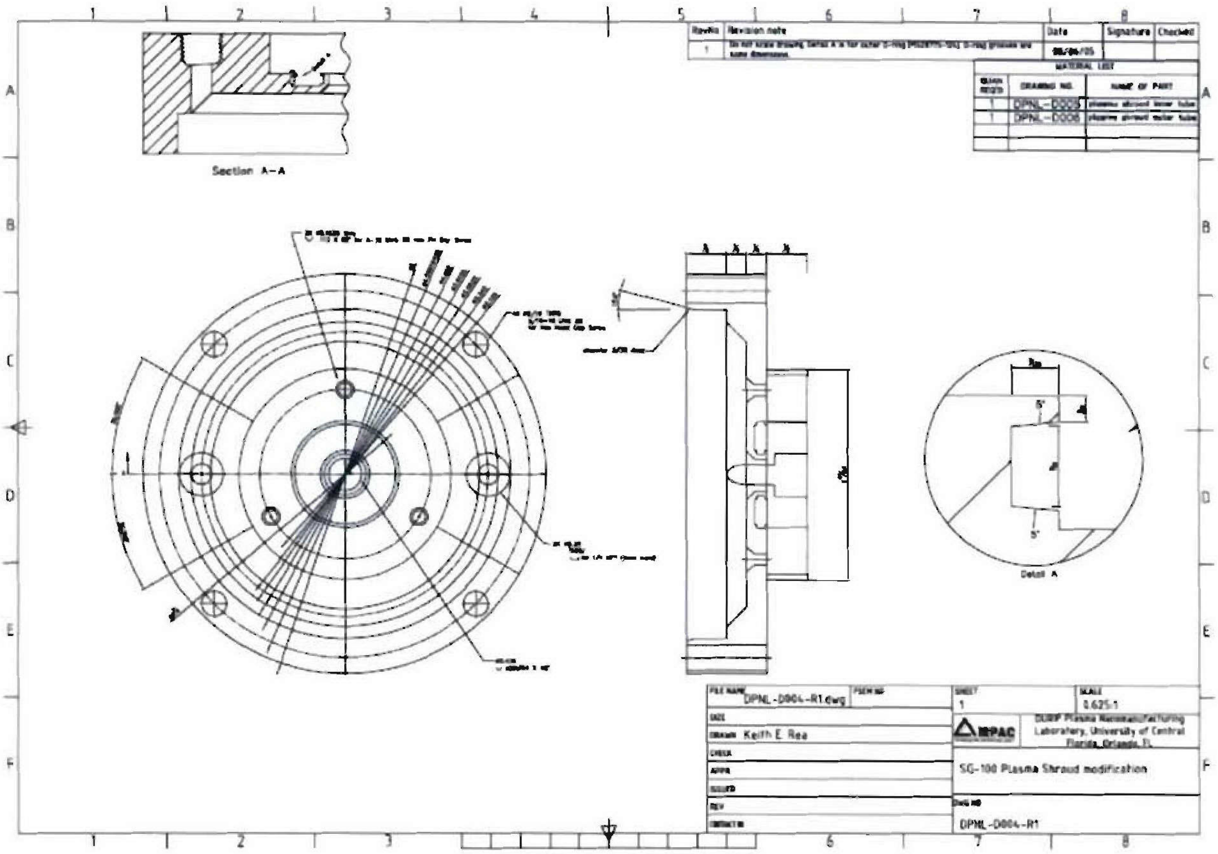

Figure 4. Orthographic drawing of the SG-100 shroud mounting plate.

The mounting plate as seen in Figure 4 utilizes the three screw holes on the SG-100 to mount the shroud assembly that were previously used for mounting a simple cooling face plate. The mounting plate forms the backbone of the shroud assembly. The inner tube makes a gaseous seal with the mounting plate and this inner tube slides inside the outer tube that makes a bolted connection to the mounting plate. The inner tube and outer tube orthographic drawings can be seen in Figures 5 and 6.

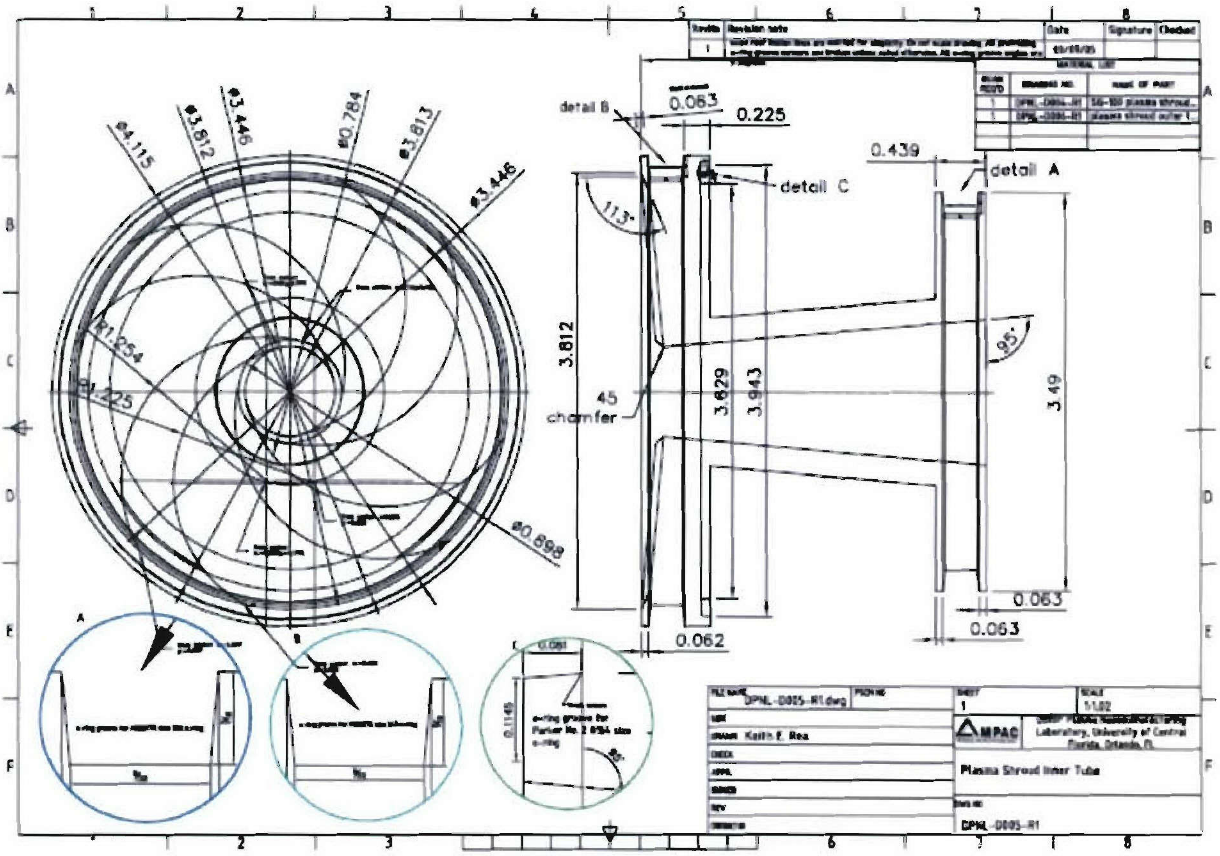

Figure 5. Orthographic drawing of the shroud inner tube.

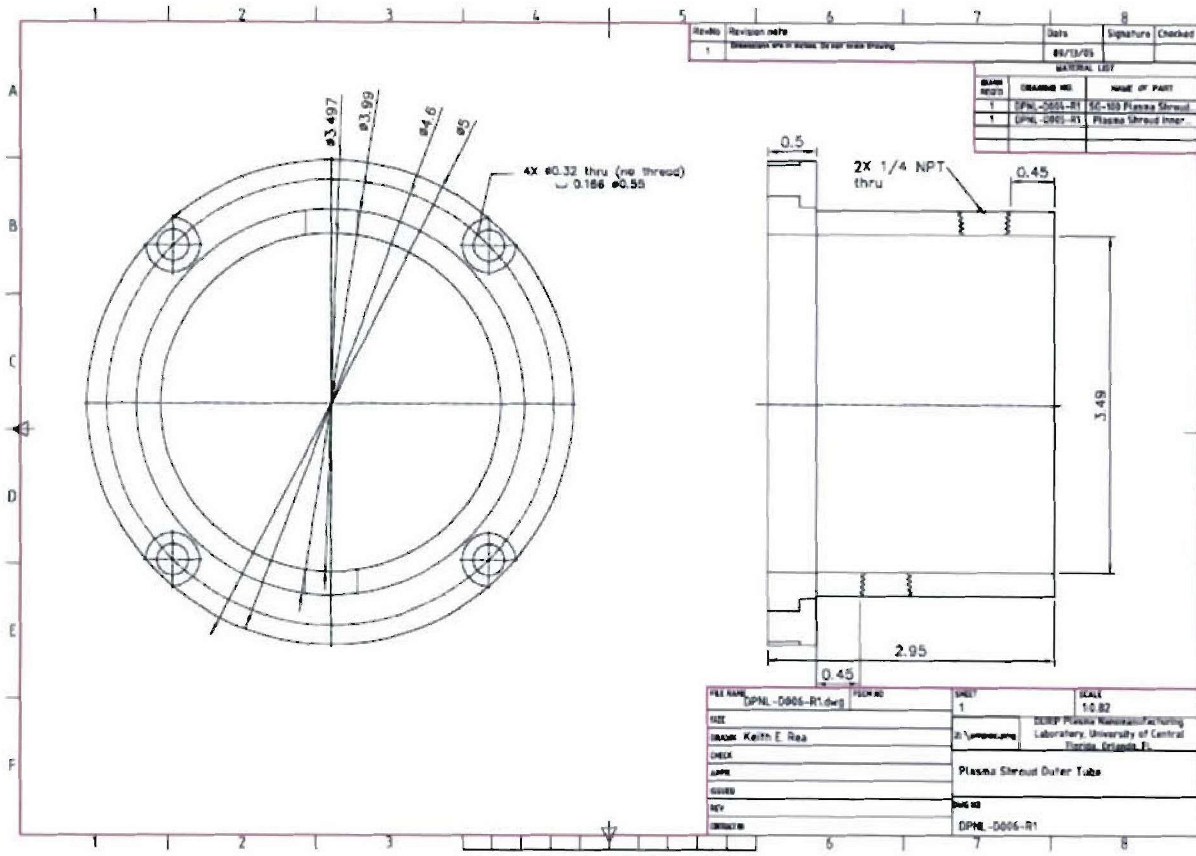

Figure 6. Orthographic view of the outer tube that houses the inner tube and connects the mounting plate.

After assembling the shroud on the SG-100 gun, the plasma flame is completely isolated from the environment until the molten particles emerge from the shroud housing and deposit on the substrate. A picture of the shroud assembly mounting plate attached on the SG-100 gun can be seen in figure 7. A further image of the shroud assembly and the SG-100 gun in operation on the robot can be seen in figure 8. The inert gas type for this initial experimentation was nitrogen, however any inert gas type can be chosen to isolate the ensuing plasma particles. The copper shroud parts are cooled using the same water chiller apparatus that were used primarily to cool the SG-100 plasma gun previously. As can be seen from the black hoses entering and exiting the assembly in figure 8. The initial test showed no signs of material degradation from the plasma flame processing or conducting heat.

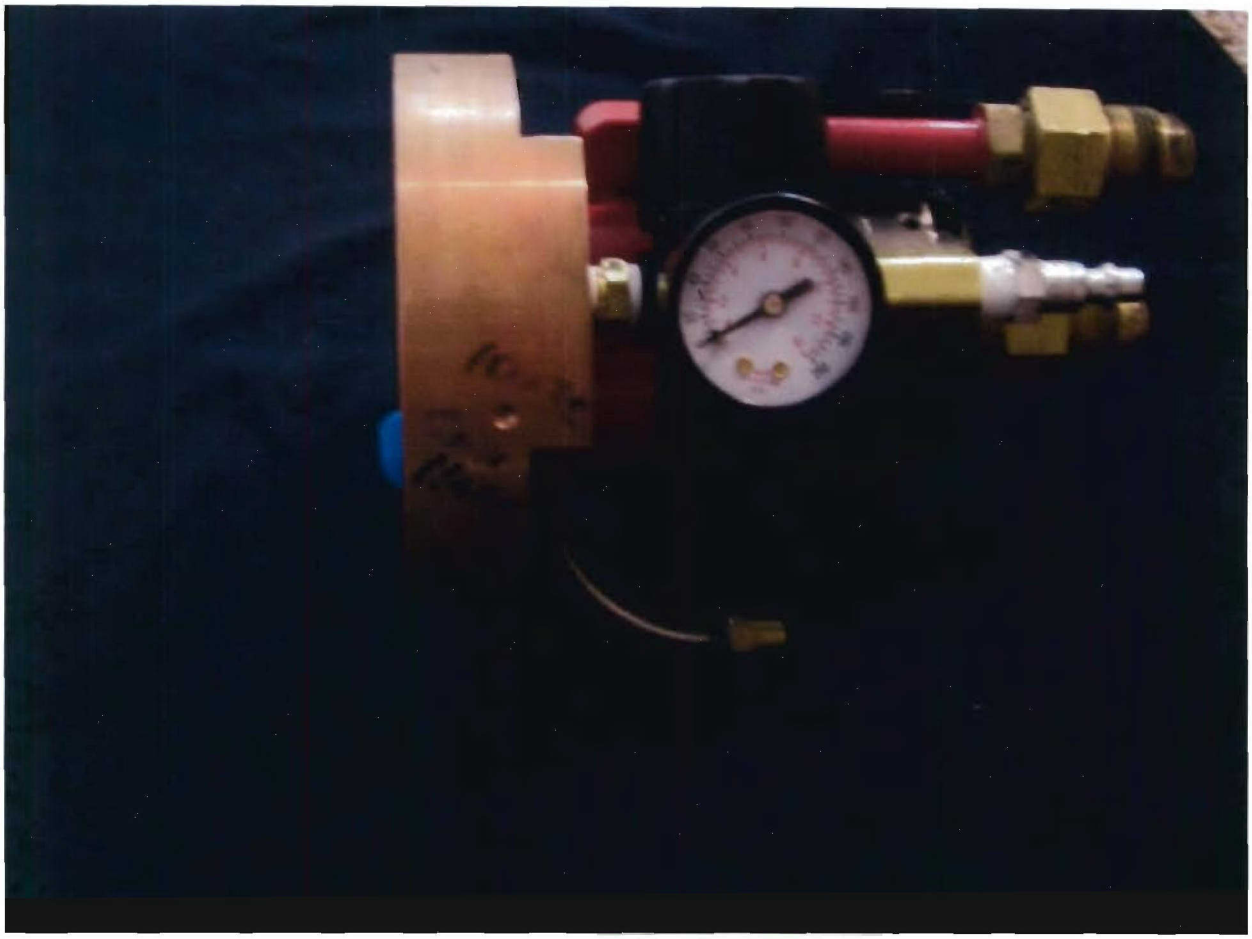

Figure 7. The mounting plate assembly mounted on the SG-100 with the shroud gas flow fitting visible in the foreground.

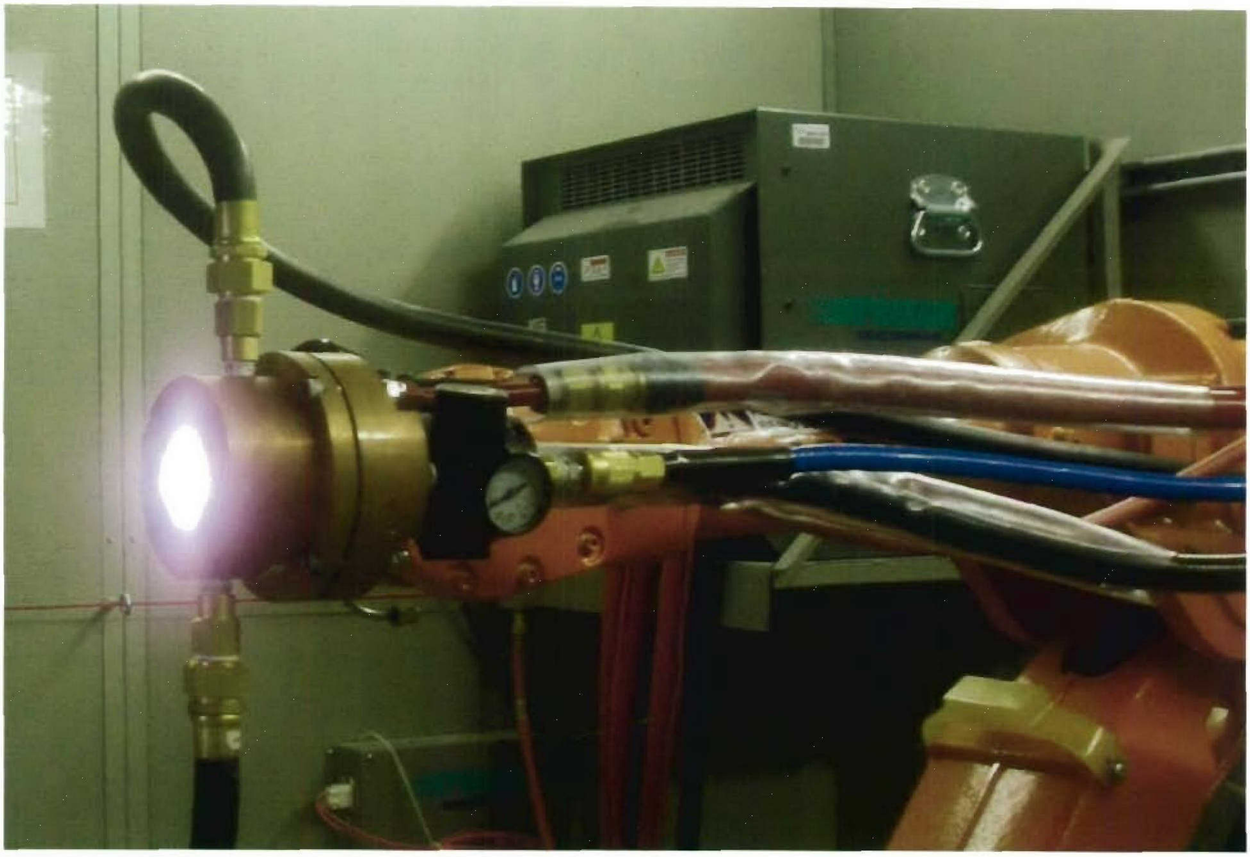

Figure 8. The plasma shroud assembly with all cooling, shrouding, and plasma operations functioning within standard spraying parameters.

3. Future Implementation

With the shroud assembly operating within standard spraying parameters, the numerous metallic systems that have had debilitating occurrences of oxidation during APS can now be sprayed with minimal interference of the elements. We further envision metal matrix composites and micro- or nano-ceramic systems that could benefit from the isolation that the shroud would provide to the rapid solidification environment.

Participants

- Dr. Sudipta Seal, Professor, AMPAC and MMAE, UCF.
- K. E. Rea, Masters Student and Graduate Research Assistant, AMPAC and MMAE, UCF.
- V. Viswanathan, Ph.D. student and Graduate Research Associate, AMPAC and MMAE, UCF

References

[1] SG-100 User's Manual, Praxair Surface Technologies, Inc. 08/2002.